

TABLE 8.—*Diurnal variation of the atmospheric electric potential; Greenwich observations; rainy and clear days.*

Hours.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
12a.....	0	-2	+1	+4	+5	+7	+5	+6	-4	-1	0	+3
1.....	-7	-3	-2	+3	+2	+5	+3	+3	-3	-5	-3	-3
2.....	-9	-9	-5	-5	+3	0	-1	+3	-6	-6	-4	-10
3.....	-11	-10	-8	-5	-7	-1	-4	-1	-9	-8	-7	-13
4.....	-14	-12	-8	-5	-9	-4	-5	-3	-10	-10	-7	-14
5.....	-13	-12	-6	-7	-8	-3	-2	-3	-12	-11	-7	-14
6.....	-14	-10	-3	-5	-5	-1	-1	-3	-12	-12	-7	-12
7.....	-10	-6	+2	+2	+4	+1	+2	-1	-9	-8	-5	-6
8.....	-8	-4	+6	+6	+6	+1	+3	0	-6	-7	-4	-12
9.....	-5	0	+2	+1	+4	-3	+1	-1	-1	-1	-3	+1
10.....	+5	+6	+2	+2	+4	+4	+9	+6	+6	+4	+2	+6
11.....	+8	+9	+6	+2	+2	+2	+5	+3	+7	+3	+3	+6
12p.....	+4	+1	0	-6	-6	-2	0	+1	+2	-1	+2	+4
1.....	+6	0	0	-5	-8	-6	-6	+7	+1	0	+1	+1
2.....	+5	-1	-3	-2	-10	-8	-9	-6	-1	0	+1	+2
3.....	+6	+2	-2	-4	-6	-3	-8	-12	-1	+2	+3	+2
4.....	+8	+8	-4	-4	-2	-4	-6	-6	+1	+9	+3	+4
5.....	+5	+7	+2	-3	+1	-4	-4	-5	+5	+10	+3	+7
6.....	+8	+9	+7	+1	+1	-2	-1	+2	+9	+12	+4	+8
7.....	+10	+9	+8	+7	+6	+1	-2	+3	+10	+9	+5	+7
8.....	+6	+7	+5	+9	+3	+3	-2	+4	+8	+5	+4	+2
9.....	+4	+6	+6	+6	+9	+6	+6	+7	+6	+5	+3	+9
10.....	+5	+6	+5	+11	+12	+10	+10	+13	+6	+7	+4	+8
11.....	+4	+3	+2	+10	+11	+9	+9	+9	+3	+5	+2	+3
12.....	+1	-3	-1	+4	+5	+6	+6	+5	0	-2	-2	+2
Means....	62	68	62	56	52	37	42	39	44	47	43	53

TABLE 9.—*Annual variation of the atmospheric electric potential; Greenwich observations; on an arbitrary scale.*

Years.	All days.	Rainy days.	Clear days.	Factor.	All days.	Rainy days.	Clear days.
1881.....	262			× 2 =	524		
1882.....	210	121	287		420	242	574
1883.....	264	152	340		528	304	680
1884.....	236	117	299		472	234	598
1885.....	234	85	328		468	170	656
1886.....	224	127	301		448	254	602
1887.....	305	176	388		610	352	776
1888.....	285	169	370		570	338	740
1889.....							
1890.....					629	433	725
1891.....					542	376	670
1892.....					465	332	557
1893.....					553	421	663
1894.....					514	358	661
1895.....					761	623	880
1896.....					661	516	768
1897.....					586	459	679
1898.....					483	342	553
1899.....					343	184	432
1900.....					450	338	539
1901.....					593	417	680

## THE OBSERVATIONS WITH KITES AT THE BLUE HILL OBSERVATORY, 1897-1902.

By Prof. FRANK H. BIGELOW.

In June, 1904, the Blue Hill Observatory published its observational data on the meteorological elements in the lower strata of the atmosphere, temperature, humidity, and wind vectors at various heights up to about 4000 meters, as derived from the kite ascensions made during the years 1897-1902, and in March, 1905, a discussion of these data by Mr. H. H. Clayton was distributed. These observations are greatly needed in American meteorology, and they constitute the first comparatively complete series of results that have been placed in the hands of students in the United States. In 1898 the U. S. Weather Bureau published in Bulletin F, compiled by Mr. H. C. Frankenfield, the results of the observations made during a six months campaign at sixteen stations in the Mississippi and Ohio valleys, besides one at Washington, D. C. These ascensions were made in the warm half of the year, May to October, and in the daytime, so that the resulting gradients are larger than can be accepted for the mean of the day and the mean of the year. Since the full problem requires the determination of the gradients for each hour of the day, and for each month in the year, in order that any application may be reliable in theoretical discussions of the circulation of the atmosphere, or in solar meteorology, those observations could not be extended to such questions. A practical handling of the Blue Hill data, comprising numerous ascen-

sions at all hours of the day and night, and in all months during five years, shows that even this amount is very meager as compared with the demands of meteorology. As a valuable contribution, however, the Blue Hill observations are welcome to students, and I am very glad to express my obligations to those who have executed this laborious investigation. A careful examination of the data leads us to believe that the ascensions were skilfully conducted, and that the results are reliable up to the degree of precision at present attainable in that class of work. My own discussion of these data, of which an account is given in the MONTHLY WEATHER REVIEW for February, 1905, "The diurnal periods of the temperature," was executed in the interval between the appearance of the first and the second parts of the work, and, hence, the results obtained by me are independent of those published in the Blue Hill discussion. Since the general conclusions are in agreement, we may be confident that the observations bear the interpretation placed upon them by Mr. Clayton and by myself, and while the scope of the treatment is different in the two cases, since I had questions of cosmical meteorology in mind, there is no important divergence in the principal results. I have sought, in my treatment of the observations, to avoid composite curves of the gradients, by discussing the data for each month of the year, as explained in my paper, intending to gain thereby a working program for the organization of the Mount Weather Observatory, and for the correlation of several outstanding problems in barometry, ionization, and magnetism of the atmosphere. As Mr. Ward has given a suitable summary of Mr. Clayton's results in Science, March 17, 1905, and as the report of my conclusions may be found in the series of papers in the MONTHLY WEATHER REVIEW, February to July, 1905, "Studies on the diurnal periods of the lower strata of the atmosphere," it is not necessary to repeat those remarks in this connection. It will be proper, however, to make some suggestions arising from these studies, with a view to their application in work of a similar kind upon the meteorological elements in the lower strata of the atmosphere.

(1) *Mixed systems of data.*—Great trouble is certain to result in meteorological studies from the indiscriminate employment of the metric system, the English system, or the English and metric systems combined. The European data are usually in the metric system, the English and the American data are generally in the English systems, but the Blue Hill data are given in a mixed system—height in meters, wind velocity in meters per second, and temperature in degrees Fahrenheit. To translate these three classes of data across from one system to the other, as is required in every cosmical investigation, adds such labor to the work as to make the difficulty of executing the research much greater than it ought to be. Obviously, we can not approve of introducing mixed systems of data into meteorology, while so much effort is being made to reduce the two primitive systems to a single system.

(2) *Gradients referred to a summit station.*—It is evident that the summits of hills or mountains offer great advantages in mechanical kite flights, over valley or low-level stations, because the prevailing winds are fresher, and this facilitates the starting of an ascension. Also, the elevated sites are somewhat freer of the irregular gusts which prevail in the surface stratum within a few hundred feet of the ground. Yet, with this advantage, there is introduced, on the other hand, an increase in the scientific complexity in handling the observed data, because the gradients in the lowest strata are very unequal, as between day and night, or from one month to another, so that the temperature-falls, or the temperature gradients referred to the summit, can not be taken as equivalent to those in the free air over a great plain, without very careful corrections. All general gradients must be corrected for the hour of the day and to a low-level surface, or the plain country, before they can be introduced into the equations of cyclones

and anticyclones. Thus, one can see by referring to my charts 14-25 in the MONTHLY WEATHER REVIEW of February, 1905, that the mean daily gradients can be found only by taking the daily means at the several levels and computing the gradients from them. Gradients referred to the summit of Blue Hill, 195 meters, will be very different from those referred to the Valley Station, 15 meters, and the gradients will differ greatly for the same day, according to the hour to which the observations refer. Much of the divergence in the published gradient data from the several countries is due to an omission to apply these principles. In the case of the Blue Hill data, the record for the Valley Station was usually published only for the beginning and the ending of a kite flight, and it was not possible to accurately interpolate the intermediate values from the report. These temperature data were courteously supplied by the observatory to the Weather Bureau by a special arrangement.

Applying these considerations to the Mount Weather Observatory, it is evident that the summit station must be supplemented by self-registering instruments at the low levels, in the Piedmont country at Trapp and Leesburg and in the Shenandoah Valley at Berryville, Winchester, and Front Royal. There is certain to be a dynamic heating and cooling effect as the wind sweeps over the summit of the Blue Ridge Mountains, and the local action of the currents must be carefully investigated. Furthermore, there is much danger of failing to deduce the correct values of the gradients from the balloon ascensions unless the temperatures at the level of the country beneath them from Bluemont to Washington and Baltimore can be secured, and unless the balloons are sent up in about equal numbers at all hours of the day and night. It is necessary to eliminate all the local conditions and the ordinary hourly variations before anything like accurate general temperature gradients can be computed.

(3) *The height of the diurnal convectional disturbances.*—Mr. Clayton seems to have assigned 2000 meters as the height at which the diurnal variation of the temperature becomes insensible, but by reference to Table XIII of his report, it is seen that the gradients in the successive 500-meter levels do not become constant for each month, as between the day and night values given in the first and second sections of the table, till the 2500-3000 stratum is passed. It has been my experience that the vertical gradients on the New England coast are generally smaller than they are in the middle valleys of the continent, and I am of the opinion that the diurnal convection reaches about the two-mile limit in many regions of the United States. Consequently, I have adopted that elevation as the limit in order to secure a system of gradients somewhat more applicable to the entire country than those strictly limited to the Blue Hill district could be supposed to represent.

(4) *The inversion of temperatures.*—One of the valuable facts brought out in these discussions is concerned with the diurnal inversion of temperatures in the lower strata. Except in mid-summer when the air is warmed up to great heights, and the ground does not cool so rapidly during the night, there is a complete inversion between the surface temperature and the air temperature at a few hundred meters above the ground, throughout the day and night, except at the hours of transition, 8 a. m. and 8 p. m., approximately. These air conditions are the results of two movements, (1) the vertical convection over a station, and (2) the horizontal movement of the cone of temperature-fall, which is very rapid from east to west with the earth's rotation. Generally the rising warm air of the day falls back to the ground outside this cone, that is during the night, and this makes a complete inversion between the day and night throughout the 24 hours. The cold temperature by day, in the air above the warm ground, consists really of the cold night air of the preceding day, and the warm air by night over the cold surface is the warm air of the preceding day lagging behind in its ascensional and its descensional path. The

semidiurnal temperature curve, however, exhibits the influence of the surface heating and cooling when the convectional currents become vigorous through short distances in elevation. These remarks may be regarded as supplementary to those contained in the Blue Hill discussion of the observations.

It will be seen that these Blue Hill kite observations are unusually fruitful and valuable in many meteorological studies, and we sincerely hope that the series may be extended to several more years, and that other observatories will add further important data of a similar kind.

## MATHEMATICAL THEORY OF THE NOCTURNAL COOLING OF THE ATMOSPHERE.

By S. TETSU TAMURA.

### I. HISTORICAL AND CRITICAL SURVEY OF THE PROBLEM OF THE NOCTURNAL COOLING OF THE ATMOSPHERE.

The problem of the cooling of the atmosphere belongs to the group of the most important, yet extremely difficult, problems in meteorology. The variation of atmospheric temperature, for instance, depends not solely upon the solar radiation, which varies with the sun's altitude and the degree of sunshine or cloudiness, but, as shown by Fourier, Poisson, Pouillet, Melloni, and others, it also depends upon the influence of the emission by the earth's surface, that is, by the soil, vegetation, snow, and ocean. Even as to the air itself, we have to distinguish the radiating power of the dry air, clouds, haze, and dust.

If the lower strata of the air are heated by the solar rays and the emission by the earth's surface, the heated air tends to rise. This results very soon in tremulous and flickering streams, which collect into larger ones. Thus the propagation of heat goes on with relative rapidity by the process of convection. The conduction of heat from the earth's surface to the atmosphere also exists, though it operates very slowly. At the same time, a portion of the heat thus communicated is lost by a process of atmospheric radiation into sidereal space. Again, the influence of the winds and rain upon the atmospheric temperature is by no means negligible. Thus, it appears that it is impossible for us, at least in the present state of our knowledge, to solve the problem by the light of modern mathematical analysis; for even the world's greatest mathematicians of the last century failed to solve the problem analytically and left to us the so-called Bessel's interpolation<sup>1</sup> formula expressed by Fourier's series, which has been criticized by Wild and Angot as too far from representing nature.

If, however, we have to deal with the problem of the nocturnal cooling of the atmosphere, or of the cooling of the calm atmosphere during long arctic nights, our problem becomes a great deal simpler. At night the earth's surface is cooled by its emission of heat into space, and the temperatures of the lower layers of the air fall, and they thus become heavier. Therefore convective movements cease to a great extent. Other disturbances also are comparatively small during the nighttime. Consequently we may consider the nocturnal cooling of the atmosphere as dependent only upon radiation and conduction of heat between the atmospheric strata and the earth's surface.

One of the first who observed the cooling of bodies exposed during the night in the open field, under a clear sky and calm atmosphere, was Patrick Wilson, of Glasgow. His observations<sup>2</sup> were made about 1783 by means of two thermometers, one placed on the snow, the other freely suspended at the

<sup>1</sup>This formula is

$$\theta = \theta_m + A_1 \sin \left( \frac{2\pi}{T} t + \phi_1 \right) + A_2 \sin \left( \frac{2\pi}{T} 2t + \phi_2 \right) + \dots$$

where  $T$  = periodic time, expressed in terms of hours.

$\theta_m$  = mean temperature of the day.

$t$  = time reckoned in hours.

$A_1, A_2, A_3, \phi_1, \phi_2, \phi$ , etc., are constants.

<sup>2</sup>Edinburgh Phil. Trans. Vol. I, p. 153.